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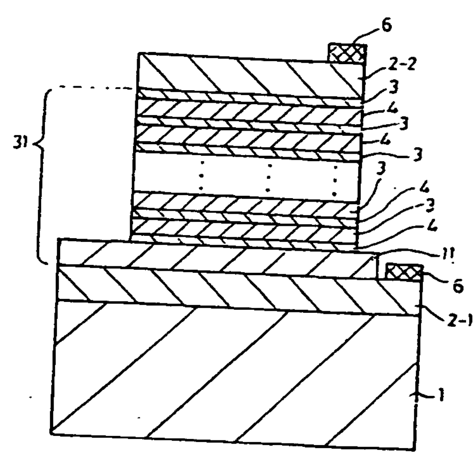
(54) Infrared detector.

(57) An infrared detector utilizing photoconduction in a multiquantum well formed of GaAs layers and AlGaAs layers. The dark current of the infrared detector is reduced by three orders or more by making one of the AlGaAs layers which form barrier layers (3) thick approximately twice that of the other barrier layers (3). Since responsivity is not substantially affected by a thick barrier layer (3), an S/N ratio is increased by one order or more.

FIG. 3



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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a photoconductive type infrared detector using a multiquantum well in which semiconductor layers whose band gaps are different from each other are alternately grown and, more particularly, to a detector which responds to far infrared rays whose wavelengths are 7 to 12 μm. With the advancement of compound semiconductor epitaxial growth technology in recent years, it has become possible to form multiquantum wells formed of GaAs type compound semiconductors, which have excellent crystal quality and whose structures and compositions are controlled satisfactorily. Infrared detectors formed from such multiquantum wells and image pickup devices with a plurality of infrared detectors arranged on a GaAs substrate have been under development.

Description of the Related Art

An infrared detector formed from a multiquantum well has been proposed (B. F. Levine et al., Appl. Phys. Lett. Vol.53, No.4, p.296 (July 25, 1988)).

As shown in Fig. 1, the above infrared detector has a construction in which are in turn formed a contact layer 2-1, approximately 1 μm thick, composed of GaAs having an electron density (n) of n = $2 \times 10^{18}/cm^3$, a multiquantum well 31 in which approximately 50 layers of a barrier layer 3, approximately 300Å thick, having a composition of non-doped $Al_{0.31}Ga_{0.69}As$, and approximately 50 layers of a well layer 4, approximately 40Å thick, composed of GaAs having an electron density of n = $2 \times 10^{18}/cm^3$, are grown, and a contact layer 2-2, approximately 0.5 μm thick, composed of GaAs having an electron density (n) of n = $2 \times 10^{18}/cm^3$. The upper contact layer 2-2 and the multiquantum well 31 are mesa-etched to expose a part of the top surface of the lower contact layer 2-1. Thereafter, an electrode 6 made of a layer of an alloy (Au-Ge) of gold and germanium is formed on the surface of both contact layers 2-1 and 2-2.

Fig. 2 shows the energy bands of the multiquantum well 31. The solid line indicates the energy level of the bottom of the conduction band. Figs. 2(a) and 2(b) show a case in which a bias voltage is not applied between th contact electrodes 2-1 and 2-2 and a case in which a bias voltage is applied between the contact electrodes 2-1 and 2-2, respectively. Reference letters E_1 and E_2 denote a ground level and a first excitation level in the conduction bands, respectively. The energy gap between these levels corresponds to 8.3 μm in terms of the wavelength of photons. Most of the electrons thermally excited into the conduction band are in the ground level E_1 in a state in which light is not incident on the multiquantum well 31. When light having a photon energy $h\nu$ ($\geq E_2 - E_1$) enters the multiquantum well 31, electrons in the ground level E_1 are excited to the first excitation level E_2 as indicated by arrow A. In a case where a bias voltage is applied between the contact electrodes 2-1 and 2-2, the electrons are moved in the conduction bands according to their polarity, as indicated by arrow C and detected as a photoelectric current (I_p).

In contrast, in a case where a bias voltage is applied between the contact electrodes 2-1 and 2-2 but light is not incident on the multiquantum well 31, the electrons 7 in the ground level E_1, which pass the forbidden band of the barrier layer 3 due to a tunnel effect, as indicated by arrow B. This tunnel current is a dark current (I_d) which is irrespective of whether light is incident upon the multiquantum well 31.

Generally, a signal to noise ratio (S/N) of an infrared detector is one of the factors which determine the sensitivity of the detector. A reduction of noise (N) is an important consideration for improved sensitivity. Noise in an electric current flowing through a semiconductor can be expressed as $N = (2qI_d)^{1/2}$ (q:electric charges of electrons). Therefore, if the dark current (I_d) is decreased, the noise (N) can be decreased. In an ordinary infrared detector, particularly a detector for detecting far infrared rays whose response wavelength is 7 to 12 μm, the dark current decreases by cooling the detector to a low temperature. However, as described above, the dark current (I_d) of the infrared detector shown in Figs. 1 and 2 is not decreased even if the detector is cooled, because the current is a tunnel current which flows through the barrier layer 3.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an infrared detector with low noise.

Another object of the present invention is to provide an infrared detector which has high detectivity by reducing a dark current without reducing a photoelectric current.

A further object of the present invention is to decrease noise without a substantial increase in the dimensions of an infrared detector.

The present invention pertains to an infrared detector having a multiquantum well, in which a tunnel current which causes a dark current is suppressed by increasing the thickness of at least one barrier layer which forms the multiquantum well. As a result, noise can be reduced without a decrease

in the photoelectric current or an increase in the dimensions of the detector.

According to the present invention, there is provided an infrared detector having a pair of contact layers grown on a substrate and electrodes in contact with the contact layers in such a manner as to be connected to an external circuit, a plurality of well layers each composed of a first semiconductor having a band gap larger than the quantum energy of an infrared ray of a predetermined wavelength, and a plurality of barrier layers each composed of a second semiconductor having a band gap larger than that of the first semiconductor, each one of said well and barrier layers being alternately grown between the pair of contact layers, and at least one layer of the barrier layers having a thickness larger than that of the remaining layers.

The aforementioned and other objects, features and advantages of the present invention will become clear when reference is made to the following description of the preferred embodiments of the present invention, together with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross-sectional view which illustrates the construction of a conventional infrared detector using a multiquantum well;

Fig. 2 is an energy band diagram of the multiquantum well in Fig. 1; Fig. 2(a) shows a state in which a bias voltage is not applied; and Fig. 2(b) shows a state in which a bias voltage is applied;

Fig. 3 is a cross-sectional view which illustrates the construction of an infrared detector of the present invention;

Fig. 4 is an energy band diagram of the multiquantum well in Fig. 3;

Fig. 5 is a graph which illustrates an effect of the decrease in a dark current according to the present invention; and

Fig. 6 is a graph which illustrates comparison of the responsivity of the infrared detector of the present invention with that of the conventional infrared detector.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Fig. 3, a contact layer 2-1, approximately 1 µm thick, composed of GaAs having an electron density of $2 \times 10^{18}/cm^3$, is epitaxially grown on the surface of a semi-insulating GaAs substrate 1 which shows (100) surface, and further a barrier layer 11, approximately 1 µm thick, composed of non-doped AlGaAs is epitaxially grown thereon. The growth of these layers may be performed by any one of the well-known molecule-beam epitaxy (MBE) process or a metal organic chemical vapor deposition (MOCVD) process.

Next, 50 layers of a well layer 4, 40Å thick, composed of GaAs having an electron density of $2 \times 10^{18}/cm^3$, and 50 layers of a barrier layer 3, 300Å thick, composed of non-doped AlGaAs, are alternately epitaxially grown, and a multiquantum well 31 is formed. The composition of the barrier layer 3 is controlled to a composition represented by $Al_{0.31}Ga_{0.69}As$ according to the desired spectral sensitivity characteristics of the infrared detector when the peak of the sensitivity is positioned at, for example, 8.3 µm. The barrier layer 11 is controlled to be the same composition as that of the barrier layer 3. Then, a contact layer 2-2, approximately 1 µm thick, composed of GaAs having an electron density of $2 \times 10^{18}/cm^3$, is epitaxially grown. The growth of these layers may be performed by any one of either the MBE process or the MOCVD process.

Next, the contact layer 2-2 and the multiquantum well 31 are mesa-etched, as shown, by lithography using a resist mask (not shown) and an etchant in which hydrofluoric acid (HF), H_2O_2 and H_2O are mixed at a volume ratio of 1:60:5000. Furthermore, a part of the surface of the contact layer 2-1 is exposed by removing the end portion of the barrier layer 11 by an etching method similar to that described above. Thereafter, an electrode 6 made of an Au-Ge alloy is formed on each of the surface of the contact layer 2-2 and the exposed surface of the contact layer 2-1 by using a well-known vacuum deposition and a liftoff method. Furthermore, heat treatment is performed, and the infrared detector of the present invention is completed. In the above mesa etching, the barrier layer 11 may be etched at the same time.

Fig. 4 is an energy band diagram of a case in which a bias voltage is applied between the electrodes 6 of the infrared detector constructed as shown in Fig. 3, with, for example, the barrier layer 11 being used as a positive polarity. A ground level and a first excitation level indicated by E_1 and E_2, respectively, are formed in the well layer 4. The ground level E_1 is positioned higher than the upper end of the band gap of the semiconductor which forms the well layer 4 and lower than the upper end of the upper end of the band gap of the semiconductor which forms the barrier layer 3. In contrast, the first excitation level E_2 is positioned higher than the upper end of the band gap of the semiconductor which forms th barrier layer 3. These levels E_1 and E_2 are determined mainly by the thickness of a well layer (e.g., the GaAs layer 4) and by the difference between the energies of the bottoms of their conduction bands of the well layer and a barrier layer (e.g., the AlGaAs layer 3).

Electrons in the ground level E_1 are excited to the first excitation level E_2 by the irradiation of an infrared ray and move in the conduction band as indicated by the arrow C. Electrons which pass through the barrier layer 3 due to a tunnel effect move as indicated by the arrow B. Since these tunnel electrons are blocked by the thick barrier layer 11, the probability that they will reach the contact layer 2-1 decreases. Therefore, the dark current (I_d) due to the tunnel electrons are reduced. Since the photoelectric current (I_p) is carried by electrons which move in the conduction band as indicated by the arrow C, it is hardly affected by an increase in the thickness of the barrier layer 11.

Fig. 5 is a graph which illustrates an effect of the decrease in a dark current according to the present invention. A bias voltage applied between the contact layers 2-1 and 2-2 is plotted in the horizontal axis, and the dark current (I_d) is plotted in the vertical axis. A curve 22 indicates the dark current characteristics of the infrared detector of the present invention. A curve 21, shown for comparison, indicates the dark current characteristics of the conventional infrared detector constructed as shown in Fig. 1 in which the thick barrier layer 11 is not provided. It becomes evident that the dark current is reduced by three orders or more by making the thickness of one barrier layer 11 twice that of the other barrier layers, as shown in Fig. 5. In addition, it can be seen that since the curve is almost symmetric from left to right, the effect is the same when the barrier layer 11 is provided in either the contact layer 2-1 side or the contact layer 2-2 side.

Fig. 6 is a graph which illustrates the responsivity of the infrared detector of the present invention. A bias voltage applied between the contact layers 2-1 and 2-2 is plotted in the horizontal axis, and responsivity, i.e., the photoelectric current with respect to unit incidence energy (A/W) is plotted in the vertical axis. White circles relate to the characteristics of the detector of the present invention, and the blackened circles relate to the characteristics of the conventional detector, which are shown for comparison. The light source is a blackbody radiation of 500K. As shown in Fig. 6, it can be seen that the photoelectric current hardly changes even if the thick barrier layer 11 is provided.

In the infrared detector of the present invention, as described above, the dark current (I_d) resulting from the tunnel electrons is reduced by making the barrier layer 11 thick. However, if all the barrier layers 3 are made thick, the following drawbacks arise: (i) the thickness of the multiquantum well 31 increases, and the infrared detector becomes larger; and (ii) the lattice scattering and recombination probability for excited electrons which pass through the barrier layer 3 will increase, and therefore th photoelectric current (I_p) is reduced. From the results of Figs. 5 and 6, it is sufficient that the thickness of one barrier layer be made large. It may be said that a conspicuous effect can be obtained when the size thereof is doubled. As described above, since the dark current characteristic curve hardly varies in response to the position of the barrier layer 11, it is clear that a thick barrier layer may be provided at a desired position inside the multiquantum well 31.

Although in the above-described embodiment a case in which the present invention is applied to an infrared detector having the multiquantum well 31 formed from a GaAs layer and a AlGaAs layer is shown, needless to say, the present invention can be applied to infrared detectors using the photoconduction in a multiquantum well formed of a combination of other semiconductor layers.

Many different embodiments of the present invention may be constructed without departing from the spirit and scope of the present invention. It should be understood that the present invention is not limited to the specific embodiment described in this specification. To the contrary, the present invention is intended to cover various modifications and equivalent arrangements included with the spirit and scope of the claims. The following claims are to be accorded a broad interpretation, so as to encompass all such modifications and equivalent structures and functions. What is claimed is:

Claims

1. An infrared detector, comprising:
   a pair of contact layers (2) which are laminated each other on a substrate 1;
   a plurality of well layers (4), each of which is formed of a first semiconductor having a band gap larger than the quantum energy of an infrared ray to be detected and which are grown between the pair of contact layers;
   a plurality of barrier layers (3), each of which is formed of a second semiconductor having a band gab larger than that of the first semiconductor, each being provided between adjacent two of the well layers (4), and at least one layer of them having a thickness larger than that of the remaining layers; and
   a pair of electrodes (6) which make an ohmic contact with each of the contact layers (2) which can be connected to an external circuit.

2. An infrared detector according to claim 1, wherein each of the well layers (4) has a ground level higher than the upper end of the band gap of the first semiconductor which forms the well layers (4) and lower than the

upper end of the band gap of the second semiconductor which forms the barrier layers (3), and has a first excitation level higher than the upper end of the band gap of the second semiconductor which forms the barrier layers (3).

FIG. 1

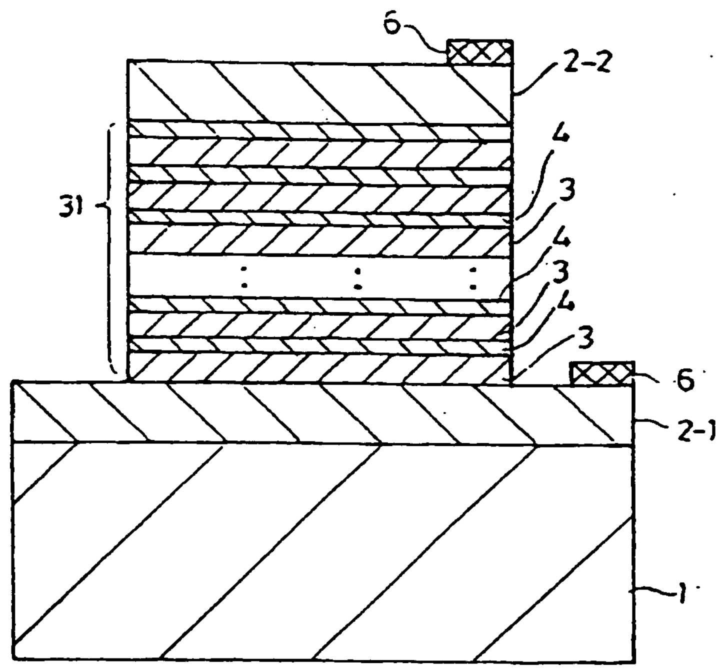


FIG. 2(a)

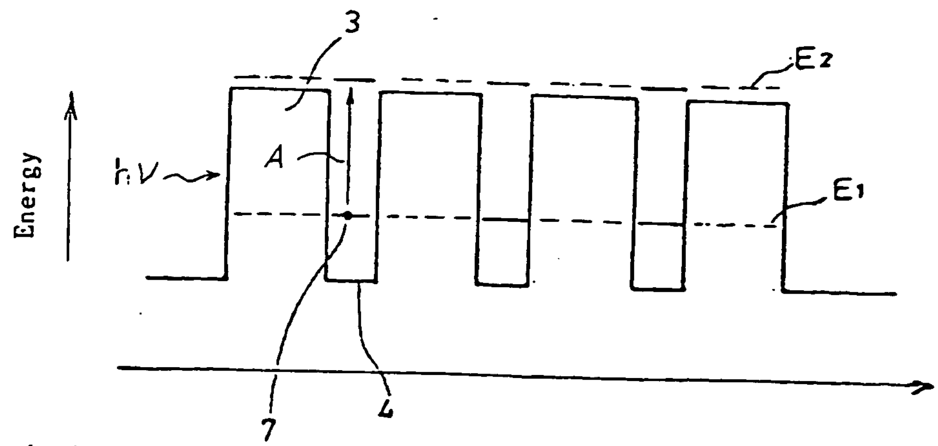

3
E2
Energy
hν
A
E1
7
4

FIG. 2(b)

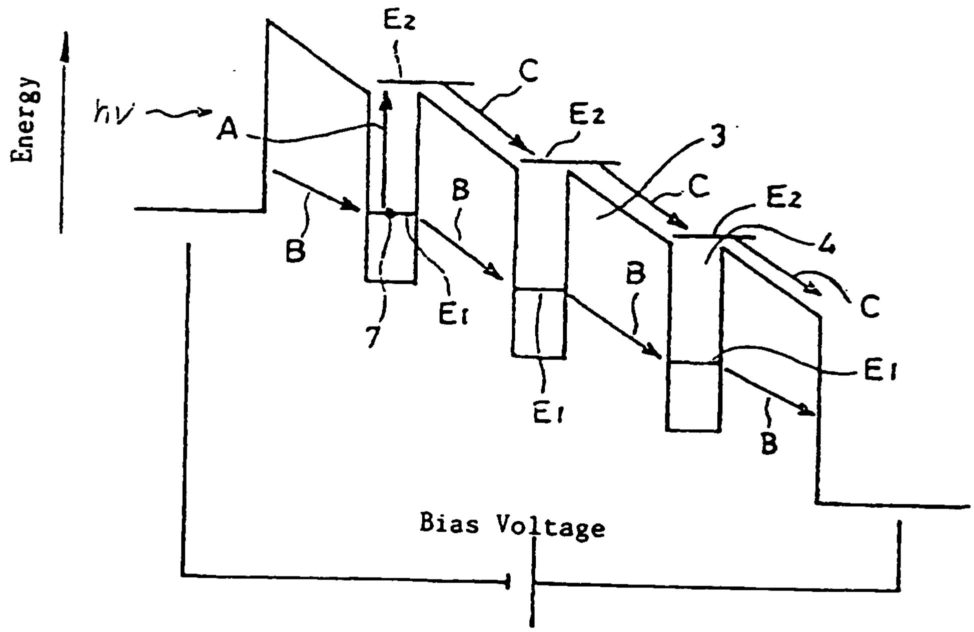

E2
C
Energy
hν
A
E2
3
C
E2
B
4
B
C
B
E1
7
E1
E1
B
E1
Bias Voltage

FIG. 3

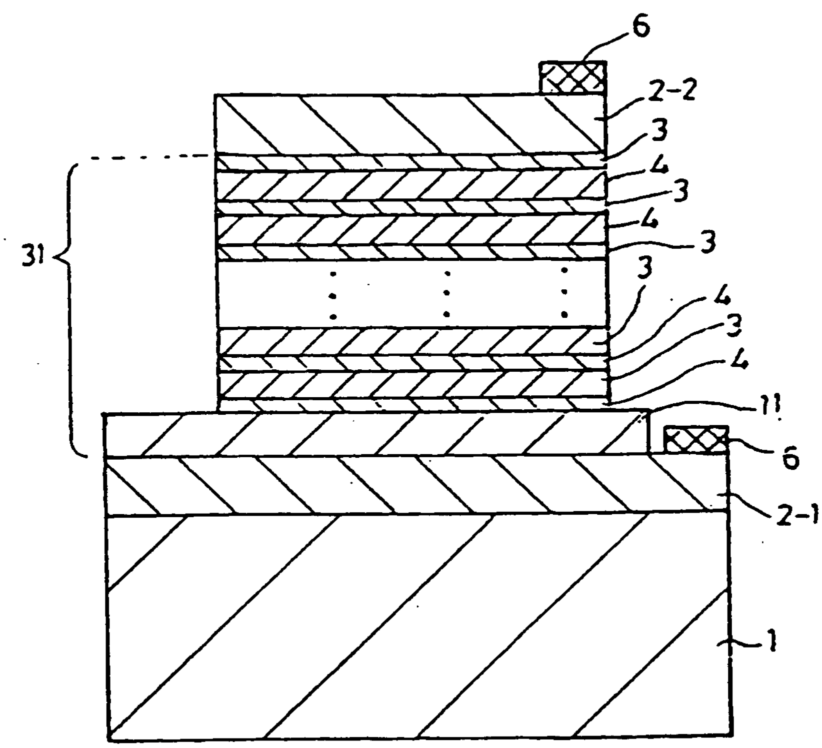


FIG. 4

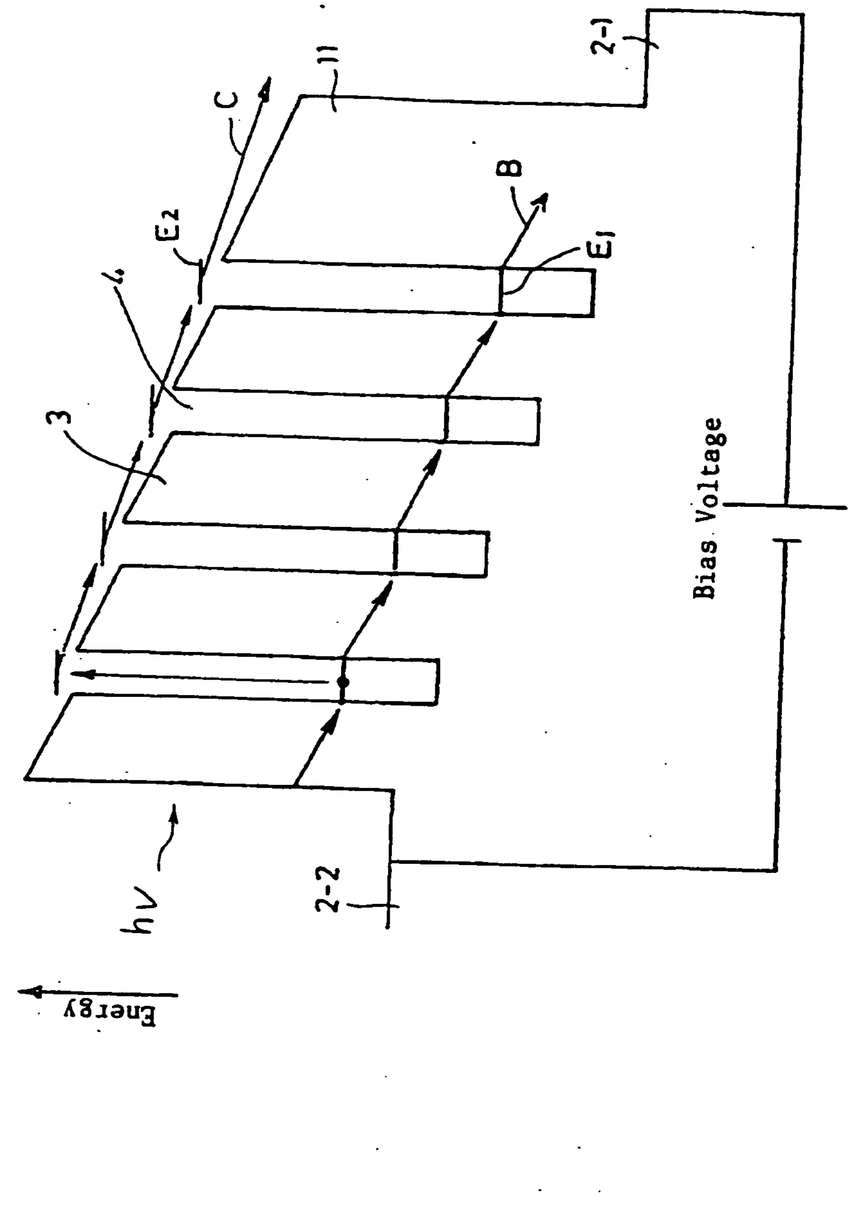


FIG.5

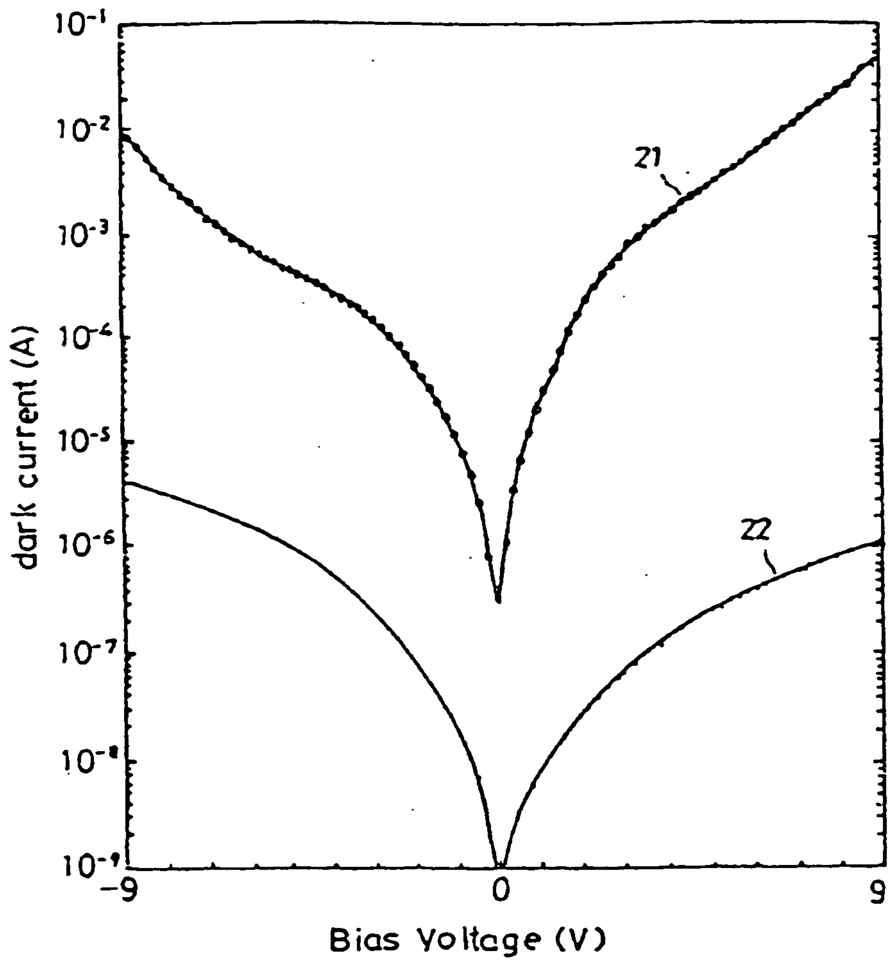
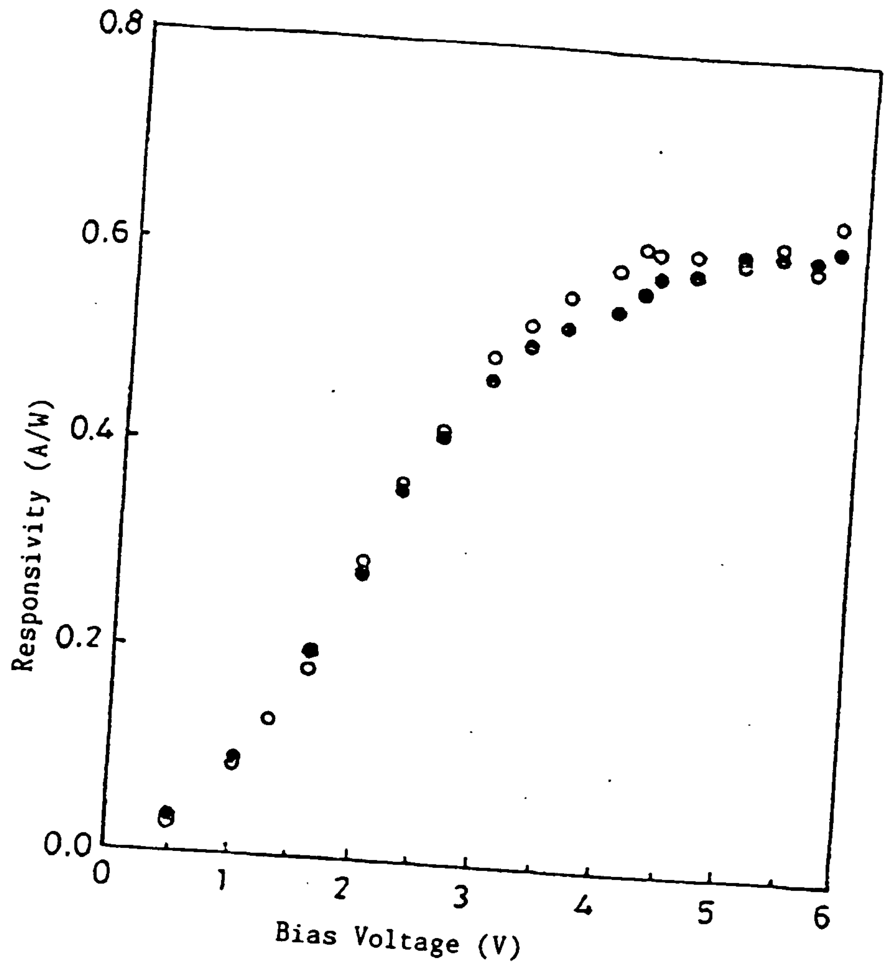

10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
dark current (A)
21
22
-9
0
9
Bias Voltage (V)

FIG.6



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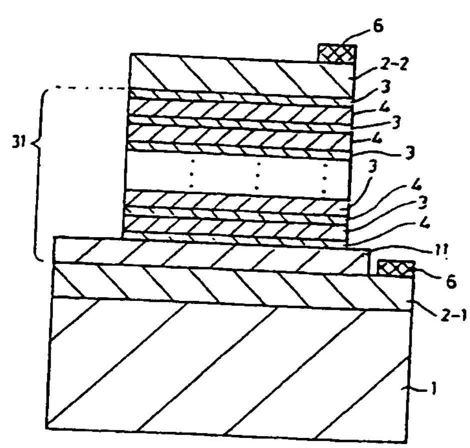
(54) **Infrared detector.**

(57) An infrared detector utilizing photoconduction in a multiquantum well formed of GaAs layers and AlGaAs layers. The dark current of the infrared detector is reduced by three orders or more by making one of the AlGaAs layers which form barrier layers (3) thick approximately twice that of the other barrier layers (3). Since responsivity is not substantially affected by a thick barrier layer (3), an S/N ratio is increased by one order or more.

FIG. 3



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European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 10 4417

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	EP-A-0 149 178 (TEXAS INSTRUMENTS INCORPORATED) * page 11, line 25 - line 32; claims * ---	1,2	H01L31/0352 H01L31/09
A	EP-A-0 345 972 (AMERICAN TELEPHONE AND TELEGRAPH COMPANY) * the whole document * ---	1,2	
A	APPLIED PHYSICS LETTERS. vol. 56, no. 9, 26 February 1990, NEW YORK US pages 851 - 853 LEVINE ET AL. 'HIGH SENSITIVITY LOW DARK CURRENT 10 um GaAs QUANTUM WELL INFRARED PHOTODETECTORS' * the whole document * ---	1,2	
X,P	US-A-5 077 593 (SATO ET AL.) * abstract * -----	1	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

H01L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29 OCTOBER 1992	LINA F.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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